

The background of the slide features a large, faint, circular seal of the Defense Nuclear Facilities Safety Board. The seal is composed of a yellow outer ring, a blue middle ring, and a white central shield. The shield is flanked by two green olive branches. The text "UNITED STATES OF AMERICA" is arched across the top of the seal, and "DEFENSE NUCLEAR FACILITIES SAFETY BOARD" is arched across the bottom. The main title is centered over the seal.

# **High Risk Operations and Natural Phenomena**

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# Introduction

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In a typical year, the Earth generates about:

- 12 million earthquakes; ~100 are extremely damaging and disruptive to society
- 100,000 thunderstorms
- 10,000 floods
- Hundreds of landslides and tornadoes
- Scores of hurricanes, wildfires, volcanic eruptions, droughts, and tsunamis
- Annual death toll ~150,000 worldwide (~200 in the US)
- Economic toll reaches ~\$156B per year (~\$52B in US)

Source: USGS, 1995



# Recorded History

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During the last 10 years the world experienced:

- 5 of the 26 largest recorded earthquakes
- 8 countries had their “worst” recorded floods
- 8 of the 20 record-setting tornadoes
- 5 of the 10 most intense Atlantic hurricanes
- Largest evacuation in U.S. history - Hurricane Rita
- Largest wildfire evacuation in U.S. history - California
- 3 of the 10 deadliest heat waves
- 2 of the 10 “deadliest natural disasters”

“Recorded history” is ~100-200 years; therefore, frequency and magnitude predictions may have large inaccuracies

# Fukushima Daiichi

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It is too early to understand the full extent of the Great Tohoku Earthquake and Tsunami, but some lessons are obvious:

- Expect loss of infrastructure during large-scale disasters
- Consider impact of large-scale disasters on workforce
- Always monitor balance of plant for secondary concerns
- Ensure that “design basis accidents” really are sufficiently conservative and challenging
- Anticipate a prolonged emergency time period
- Robust design and construction are keys to success
- Plan, plan, plan for emergencies



# Loss of Infrastructure

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A common element of large-scale disasters is the indefinite loss of local infrastructure. This may have several affects:

- Loss of off-site communications, utilities, medical, police, and emergency services
- Lack of information on extent of damages, residual risks and vulnerabilities, or available response assets
- Loss of coordination with civil authorities regarding actions such as initiating a public evacuation
- Loss of access to staged or backup equipment, replacement supplies, consumables
- Lack of personnel - off-site staff may not be able to respond to recall



# Impacts on Workers

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Large-scale disasters have severe impacts on workers:

- Uncertainty about safety of family and friends and status of home and possessions is huge distraction
- Trauma-induced stress increases rate of human error and reliance on rote learning
- Prolonged stress and insufficient rest is unhealthy and impacts reasoning and decision-making skills
- Perception of urgency encourages ad hoc behavior rather than disciplined conduct of operations

Emergency activities require higher level of checks and balances to compensate for higher potential for error



# Hidden Damage

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- A large-scale event may cause hidden damage to the facility; focusing only on identified failures may confuse operators or distract them from other systems
  - Eastern Airlines Flight 401 indicator light, 1972
  - TMI-2 pressurizer water level, 1979
- Emergency procedures must ensure that all of the facility is being adequately monitored or attended to
- Adequate resources should be available to address simultaneous accidents if the potential exists
- Consider borrowing the concepts of Crew Resource Management (CRM) from airline industry



# Design Basis Scenarios

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- We must ensure that design basis accident scenarios represent *what may happen*, not *what has happened*
- We must understand the uncertainties in using 100-200 years of recorded history to predict to  $1 \times 10^{-6}$ /year
- We must not assume a priori that past accident experience defines the bounding accident scenario
- We must consider the impacts of common mode failures
- We must consider what is happening *around the plant* when we analyze what is happening *inside the plant*
- We must consider incorporating Severe Accident Management concepts into analysis and design



# What DID history show in 1970?

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Design basis seismic event for Fukushima was set before 1970.

Very little was remembered about how big tsunamis can be. Most research was after 1990.

“Lost in the mist of time”

Actually, how frequent were very large tsunamis off Japan's east coast?

# Japanese Tsunamis Since 1900

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## **Date: Location: Fatalities:**

Aug-10-1901 Japan (Sanriku) 18

Jul-07-1905 Japan (Fukushima) 41

Jan-12-1914 Japan (Seikaido) 35

Sep-01-1923 Japan (Tokaido) 2,

144 Mar-07-1927 Japan (South-West Honshu) 325

**Mar-02-1933 Japan (Sanriku) 3,000**

May-29-1938 Japan (Hokkaido)

# Japanese Tsunamis Since 1900

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Aug-02-1940 Japan (Hokkaido) 7

Nov-18-1941 Japan (Seikado) 2

**Dec-21-1946 Japan (Nankaido) 1,997**

Mar-04-1952 Japan (Southeast Hokkaido) 33

May 16-1968 Japan Trench 52

May-26-1983 Japan (Noshro) 103

Jul-12-1993 Japan 120

Source: [www.btinternet.com/~mike.ferris/tsunami.htm](http://www.btinternet.com/~mike.ferris/tsunami.htm)

Not exactly Rare Events!

# 1896 Meiji-Sanriku Earthquake

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(from Wikipedia)

On June 15, 1896, nearly 22,000 Japanese lost their lives due to one of the most devastating tsunamis in Japanese history

The tsunami, which was generated by the earthquake off the coast of Sanriku, Japan, attained a height of 25 meters . Sanriku is 188 nm from Fukushima Daiichi

A successful model was published in 1996: *Geophysical Research Letters* **23** (3): 1549–1552. “If a substantial earthquake occurs in the same area in the future, a resulting tsunami could be unusually large, like the 1896 event”

# If this had been Design Basis in 1971....

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TEPCO design was up to all current standards. Atomic Energy Commission, later Nuclear Safety Commission was correct to grant the license,

But research marches on.

Between 2005 and 2007, three Japanese nuclear power plants were shaken by earthquakes that far exceeded the maximum peak ground acceleration used in their design

A government-sponsored committee issues the 2006 *Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities*

# 2006 Revised Seismic Hazard Analysis

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Japan Electric Association had 11 of its committee members on the 19-member government subcommittee Professor Katsuhiko ISHIBASHI of Kobe U. resigned from committee in protest that standards for surveying active faults were not being reviewed



# Hindsight

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- In hindsight, what could be recommended for the future?
- Breakwater would have been designed to 25 m instead of 5.5 m, the JSCE guideline of 2000. Plant level would have been higher than 10 m above sea level for plants 1-4
- EDG and switchgear would have been situated above 25 m
- General rule: Dirt and concrete are cheap. Always build it much bigger than you need
- Don't automatically expect that your experts are always right.
- Risk~(life of facility/return period of design basis tsunami at this location)?

# Other LL Opportunities

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- *Ocean Ranger* Drill Rig capsizes in cyclone, 1982
  - Insufficient preparation for responding to emergency
  - Inadequate life safety equipment
- Hurricane Katrina & Flooding of New Orleans, 2005
  - Loss of infrastructure impacted ability to respond
  - Inadequate coordination between responding agencies
  - Insufficient planning for evacuation
- Sayano-Shushenskaya Hydroelectric Dam Accident, 2009
  - Insufficient preparation for station blackout conditions
  - Inadequate life safety equipment



# Recommendation 2004-1

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- This recommendation was born from the *Columbia* disaster and the near-miss at the Davis-Besse NPP
- The CTA concept was perceived as a defense against marginalization of nuclear safety requirements
- The delegation of authority review was intended to ensure that risk-based decisions were made with adequate technical understanding
- The emphasis on nuclear safety R&D was intended to reduce uncertainties in accident analyses

**Are we getting the outcomes we envisioned from the implementation of Recommendation 2004-1?**

# Suggested for DOE Research

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- Are uncertainties in postulated accident progressions, consequences, and controls adequately understood?
- Are facility designs sufficiently robust to compensate for those uncertainties?
- Have emergency plans and preparations adequately addressed the spectrum of accidents that could occur?
- Do emergency drills and training efforts sufficiently challenge the operators and preparations?
- Do sufficient plans exist for the early-phase recovery of facilities after severe accidents?
- Have the *Deepwater Horizon* and Fukushima Daiichi accidents been formally analyzed for lessons learned?

# Conclusion

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**“An operator must never be placed in a situation which an engineer has not previously analyzed.”**

(Ed Frederick, control room operator for TMI-2)